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NOVEL MECHANICAL WEED CONTROL IN ORGANIC CROP PRODUCTION

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Novel Mechanical Weed Control in Organic Crop Production

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1&2) Abstract and Executive Summary

In general, cereal crops show good tolerance to in-crop harrowing in the absence of weeds. Favorable growing conditions allowed the crops to compensate for large amounts of burial. Oat is as tolerant to in-crop harrowing as barley and more tolerant than wheat. Because of this, the recommendation to avoid in-crop harrowing in oat should be revised. In crop harrowing was relatively ineffective at controlling wild oat and wild mustard. This lack of control is probably a function of the biology of these species. As we have not included a harrowing treatment when these weeds are just emerging, they were able to re-grow after the harrowing. In some cases weed species responded differently to timings of mechanical weed control operations thereby obscuring any positive yield benefits. The crops exhibited tolerance to in-crop mowing up to the 4.5 leaf stage. Following this stage yield was reduced greatly. Mowing at the 4.5 leaf stage and later reduced broadleaf weed biomass but increased grassy weed biomass. Because of this effect and the poor crop tolerance, mowing did not result in a yield increase when weeds were present. Flax was tolerant to rolling up to the 20 cm stage in the absence of weeds. After this stage yield losses occurred. Rolling showed some control of wild mustard when preformed when the flax was flowering. Despite this, rolling flax during flowering reduced flax yield compared to the un-rolled control. Because of this we recommend that growers not roll flax for weed control. Spring wheat tolerated rotary hoeing at all stages. Under weed-free conditions, wheat heads per square meter declined slightly with increasing number of passes; however, this did not result in lower yields as the crop was able to compensate. Hoeing at the 1-2 leaf stage was the optimum stage for reducing weed density in 2005 and achieving highest yields in 2004 and 2005. Two to four passes with the rotary hoe resulted in highest yield depending on year. Overall cereal crops are quite tolerant to in-crop harrowing and rotary hoeing. Further research needs to be done on the tolerance of these crops to earlier mechanical weed control operations at emergence and the one leaf stage. Further research also needs to be done to optimize the timing of weed control operations for individual weed species based on their growth stage.

3) Technical Report
Background

The Saskatchewan organic industry is rapidly expanding with a 64% increase from 1999 to 2000 (Macey, 2002). In 2000 approximately 2% of all farms in Saskatchewan were organic (SAF 2000). As synthetic inputs are not allowed in organic crop production systems, producers must rely on cultural and mechanical weed control methods. As a result weed control under organic conditions can be challenging. A weed survey of 5% of the organic farms in Saskatchewan conducted in the summer of 2002 found that grassy weeds such as green foxtail and wild oat were common in organic agriculture. Perhaps not surprisingly broadleaf weeds that are easily controlled by herbicide in conventional agriculture have high populations in organic fields (SAF 2003). In particular, wild mustard, lamb's quarters and wild buckwheat were weeds strongly associated with organic agriculture. The organic agriculture sector has recognized the

need for research in organic weed control methods. The 2001 Organic Industry Needs Assessment study found that weed control was the number 2 research priority for crop production (SAF, 2001). Mechanical weed control can provide reasonable levels of weed control. Previous research has found that harrowing and rod weeding can be effective in controlling weeds pre- and post emergent in field pea (Johnson, 2001). Nonetheless there are few tested recommendations on the timing, selectivity and efficacy of post emergent mechanical control methods. Post emergent in crop harrowing is frequently practiced by organic farmers for weed control. However, there are no recommendations in many crops for the timing and number of applications necessary. Rotary hoes have been used in organic agriculture but they are impeded by crop residue. High residue rotary hoes exist but there efficacy and crop tolerance has not been evaluated in western Canadian crops. In addition, there are several novel mechanical control methods that have not been evaluated only have only vague testimonial recommendations. Mowing the crop and weeds and allowing crop re-growth may allow post emergent weed control without tillage. It has been suggested that this technique would work best with barley or oats. Rolling of flax to break the stems of broadleaf weeds is another method which may allow non-tillage based post emergent organic weed control. The idea is that flax has a high fiber stem that allows it to bend without breaking. To evaluate and refine these methods for use by organic farmers requires that both the weed control efficacy as well as the crop tolerance of these methods be evaluated. Once the recommendations of this study are known a fact sheet clearly outlining how to use the recommended mechanical control practices will be produced.

Environmental data

Both Scott and Saskatoon received much more growing season precipitation in 2005 that the long term average (Table 1). Some of that precipitation fell as hail on July 13 at Scott in a storm that severely affected the growing conditions

TABLE 1: Growing season precipitation (mm) and mean monthly temperatures (° C) at Scott and Saskatoon, 2004-2006.

Location	Year	*Precipitation (mm)*					
		April	*May*	*June*	*July*	*August*	*Total*
Scott	2004	3	35	53	69	44	204
	2005	27	41	100	77	88	333
	2006	32	63	46	35	47	223
	Long-Term Avg.	23	36	60	59	45	223
Saskatoon	2004	18	36	87	75	73	289
	2005	76	31	110	55	62	334
	2006	27	58	111	46	35	277
	Long-Term Avg.	14	47	61	60	39	221

		Mean Monthly Air Temperature (° C)					
		April	*May*	*June*	*July*	*August*	*Avg*
Scott	2004	5	8	13	17	14	11
	2005	5	9	14	18	13	12
	2006	7	11	15	19	17	14
	Long-Term Avg.	3	10	15	17	16	12
Saskatoon	2004	6	8	13	17	14	12
	2005	6	10	14	18	15	13
	2006	7	11	16	20	18	14
	Long-Term Avg.	4	11	16	18	17	13

Materials and Methods

The hypothesis of this research is that novel mechanical weed control practices can control weeds with acceptable crop tolerance. Therefore our objectives were to evaluate the crop tolerance and weed control using these methods. These two criteria were evaluated in separate experiments for each weed control method in order to not confound the results. The crop tolerance studies will be kept weed free with herbicides. Weed control was assessed with the test crop present and with additional weeds planted to supplement the natural weed community.

All data was checked for homogeneity of variance using Levene's test. Data that did not have a homogenous variance structure was transformed prior to analysis using either a square root or log transformation. Except where noted back transformed data is presented. The data were analyzed using a hierarchal mixed model analysis of variance. The covariance model fit was optimized by selecting covariance structures which minimized the Akaike Information Criterion (AIC). This often meant leaving non-significant effects out of the model and modeling the data using regression analysis. AIC's were compared for model fits using a chi squared test. Site and year were treated as random effects and data was analyzed combined whenever possible. When site-year by variable interactions were encountered they were inspected to see if the individual site years had contradictory results. If they did not the data was kept combined to increase the inference potential of the experiment. Only significant effects are presented ($P< 0.05$) except where noted.

Experiment 1.a. Tolerance of Cereal Crops to Flex-Tine Harrows (Saskatoon and Scott

Equipment: A flexi-tine weeding harrow
Crops: Barley, Wheat, Oat
Treatments:
1.1. Crop tolerance
1.1.1. Harrow passes a) 1 pass b) 2 pass c) 3 pass d) 4 pass
1.1.2 Crop stage: a) 2 leaf stage b) 4 leaf stage c) 6 leaf stage
All expereiments done in the absence of weeds.

Results and Discussion:

Table 2 shows the test of fixed effects for the combined factorial analysis of all five site years at Saskatoon and Scott. All crops tolerated quite high levels of harrowing and burial in the absence of weeds. However, wheat was less tolerant than oat and barley to in-crop harrowing at the 2 and 4 leaf stage (Figure 2). This lowered tolerance was likely because burial of wheat was greater than the other crops (Figure 1). Interestingly the relative yield of oat was as affected by harrowing did not differ from barley and was greater than wheat. At the onset of this experiment oat was not recommended for in-crop harrowing. Well it has been difficult to determine where that recommendation arose from we can speculate that may have been assume that oat was less tolerant to in crop harrowing because the relative position of the crown is closer to the soil surface than in wheat and oat. However, this clearly does not affect the tolerance of oat to in crop harrowing. Producers who grow oat and who wish to use post emergence in crop harrowing as a weed control method can do so with the knowledge that oat is more tolerant to harrowing than wheat.

Although harrowing the crop earlier resulted in greater crop burial the crop was more tolerant to burial at early stages. Harrowing at the two leaf stage resulted in greater burial than the four or six leaf stage (Figure 3). However, crop yield was not reduced as much at the two leaf stage presumably because the crop had time to recover (Figure 2).

The relative yield of the crop species as affected by harrowing seems to be associated with the average burial. Wheat had the greatest crop burial (Fig 1) and the lowest relative yield (Figure 3). Wheat probably was buried more because of the smaller leaves that it was observed to produce compared to barley and oat. Leaf morphology can have an effect on the tolerance of a crop to harrowing.

Increasing the number of harrow passes increased the crop burial in a linear fashion (~6% for each pass at the 2 and 4 leaf stage), however the first pass caused the majority of the crop burial (Figure 3). The increase in burial caused by more harrow passes causing a slight linear decline in the yield of all crops (Figure 4). Thus the most potential weed control probably results from the first harrow pass. For example the first harrow pass at the two leaf stage caused on average 64% crop burial. Adding an additional pass only increased burial to 70%.

In 2006 at Saskatoon harrowing at the crop emergence stage ("ground crack") was added as a treatment to this experiment. Interestingly the crop yield was similar when harrowed at ground crack compared to being harrowed at the two leaf stage. As this is only one site year of data we cannot comment further on this timing or harrowing.

In conclusion all cereal crops are tolerant to in-crop harrowing over a wide range of stages and passes. Barley and oat maintain yield better than wheat when harrowed. The yield reduction caused by harrowing seems to be related to the proportion of the crop that is buried as wheat was buried more by harrowing than the other two cereals.

TABLE 2. Test of fixed effects (Pr>F) for combined factorial analysis of the five site-years.

Source	Relative Yield	Burial (%)	Relative Head density
Crop (C)	0.2008	0.0221	0.2045
Passes (P)	0.0191	0.0001	0.1478
Stage (S)	0.003	0.0011	0.0017
C*P	0.3299	0.3656	0.7191
C*S	0.0233	0.4933	0.229
P*S	0.8076	0.0002	0.4819
C*P*S	0.8361	0.8517	0.9947

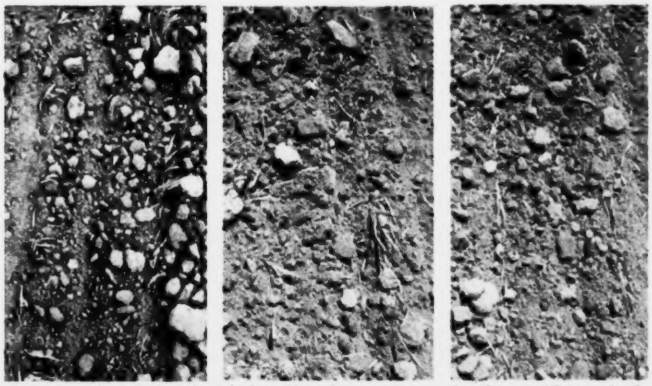


FIGURE 1. Crop burial of barley, oat and wheat (from left to right) after four passes at the two leaf stage. Averaged over all treatments, crop burial of wheat (57%) was significantly greater ($P<0.05$) than barley (44%) and oat (38%).

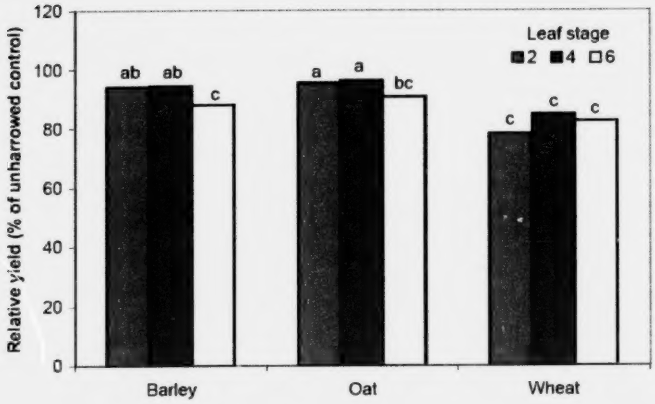


FIGURE 2. The yield of barley, oat and wheat relative to the un-harrowed control as affected by leaf stage. Average of five site years. Means with a same letter are not significantly different (P<0.05).

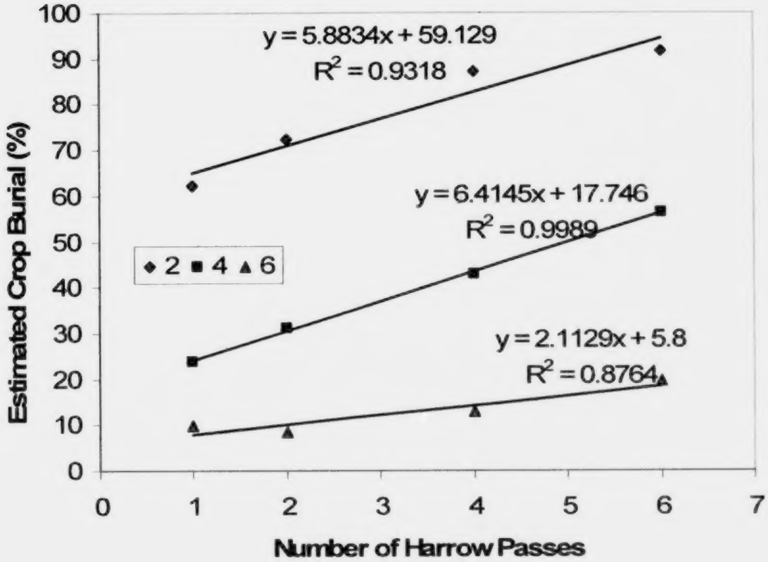


FIGURE 3. The effect of number of harrow passes at the 2, 4 and 6 leaf stage on the estimated crop burial. Crop burial was estimated visually following harrowing treatments.

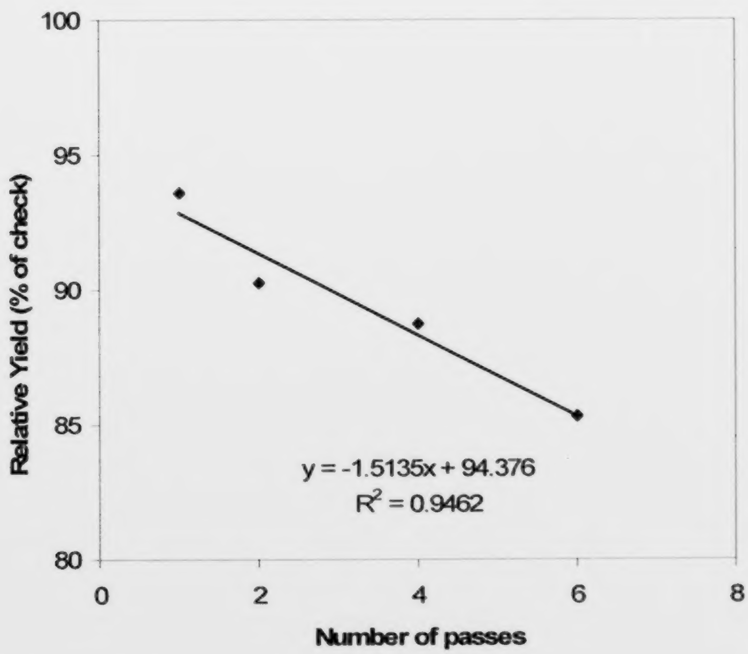


FIGURE 4. Effect of number of harrow passes on the average yield of wheat barley and oat. Note that the Y axis does not begin at zero.

Experiment 1.b. Weed Control in Wheat by Flex-Tine Harrows (Saskatoon and Scott)

Equipment: A flexi-tine weeding harrow
Crops: Barley, Wheat, Oat
Treatments:
1.2 Weed Control
1.2.1. Harrow passes: a) 1 pass b) 2 pass c) 3 pass d) 4 pass
1.2.2 Crop stage: a) 2 leaf stage b) 4 leaf stage c) 6 leaf stage

Results and Discussion:

Averaged over all site years harrowing had no effect on crop yield (P=0.41). Within individual site years there were some yield effects. At Scott in 2004 and 2005 the harrowing treatments had an average yield greater than the un-harrowed controls of 124 kg/ha (Contrast P=0.07) and 183 kg/ha (Contrast P=0.0025) respectively. However, there was no detectable pattern in the small yield benefits that came from harrowing. In some environments one or two early harrowing at the two leaf stage resulted in the greatest yield relative to the control whereas in other environments six harrow passes at the six leaf stage resulted in the greatest yield (data not shown). Because of these inconsistencies we are unable to make any recommendations on harrowing based on the yield of the crop.

Post emergence harrowing affected the weed biomass. The effect of harrowing on wild oat biomass was best described by a linear model relating number of passes (P=0.0428) and crop leaf stage (P=0.0681) to wild oat biomass (Figure 5 and 6). Each harrow pass reduced wild oat biomass by an average of 26 g/m^2 (Figure 5). However, the first harrow pass actually slightly increased wild oat biomass and it is not until there are two harrow passes that wild oat biomass is lower than it is in the control. Harrowing wild oat at latter leaf stages reduces biomass. For each leaf stage past the two leaf stage that wild oat is harrowed the biomass is reduced on average by 52 g/m^2 (Figure 6). Nevertheless, harrowing at the two leaf stage slightly increased wild oat biomass. Based on the linear relationship a farmer could expect to lower the wild oat biomass by 23% by harrowing two times at the six leaf stage. Increasing the harrow passes to four times would result in a wild oat biomass reduction of 32%.

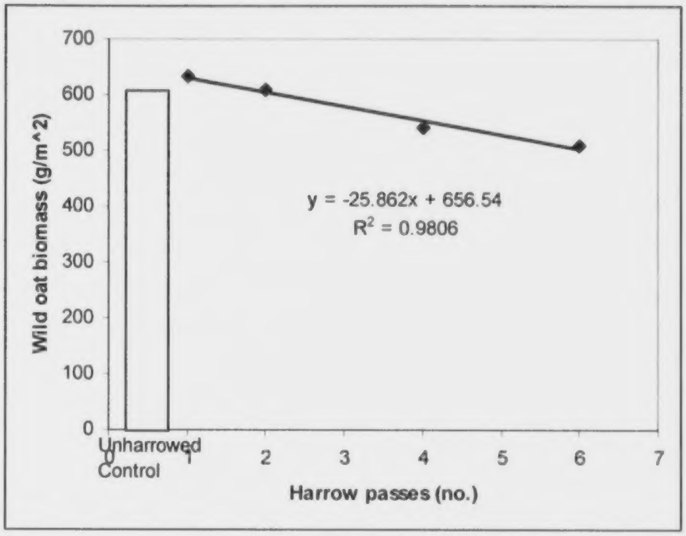


Figure 5. The effect of number of harrow passes on wild oat biomass. The bar is the wild oat biomass in the unharrowed control. Average of five site-years.

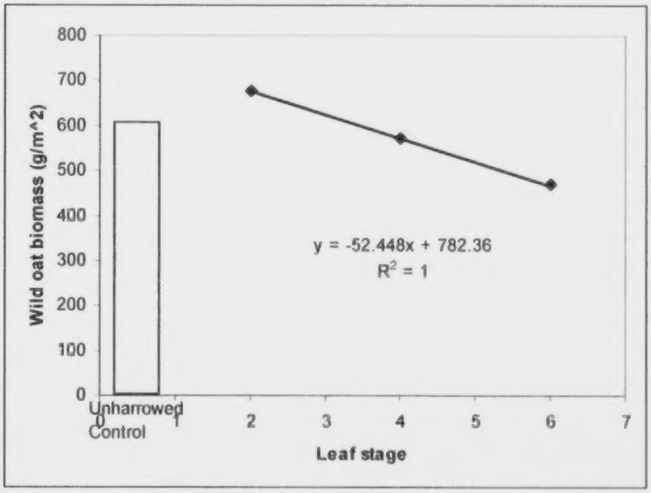


Figure 6. The effect of crop leaf stage of harrowing on wild oat biomass. The bar is the wild oat biomass in the unharrowed control. Average of five site-years

The reaction of wild mustard biomass to harrowing differed markedly from wild oat. Wild mustard biomass was reduced the most by harrowing at the two leaf stage of the crop (P=0.0653) (Figure 7). Harrowing wild mustard at the four and six leaf stage of the crop had no affect on the wild mustard biomass. The number of passes reduced wild mustard the most when wild mustard was harrowed four times (P=0.0428). However, the effect of number of passes on wild mustard biomass shows no discernable pattern. Overall harrowing wild mustard at the two leaf stage resulted in a 35 % reduction in wild mustard biomass.

The contrasting effect of harrowing on the weed biomass may explain why there was little positive response in yield. Wild oat biomass was reduced most by harrowing at later crop leaf stages (Figure 5) whereas wild mustard biomass was reduced most by harrowing at early leaf stages. As we assessed these two weeds in the same plots it

can be postulated that any positive yield benefit accrued by reducing biomass of one weed was cancelled out by the opposite response of the other weed.

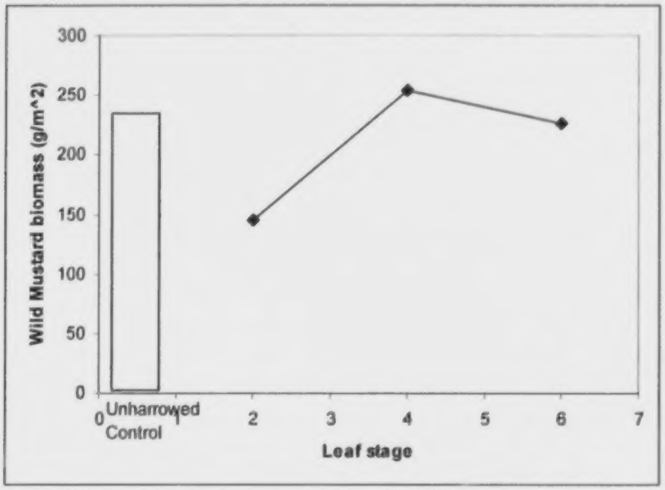


Figure 7. The effect of crop leaf stage of harrowing on wild mustard biomass. The bar is the wild mustard biomass in the unharrowed control. Average of five site-years.

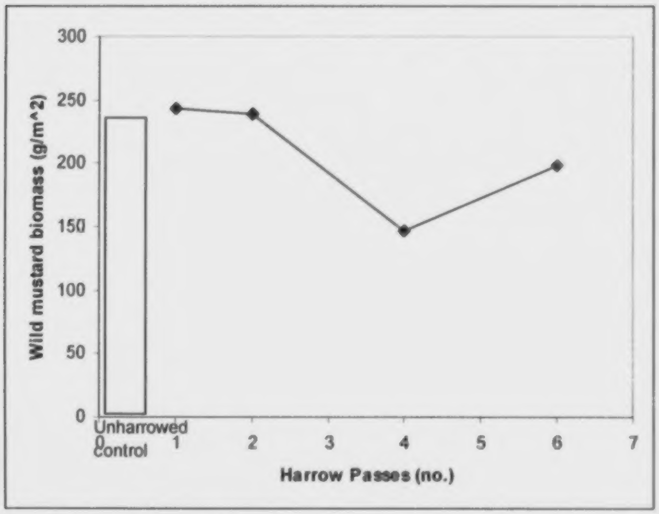


Figure 8. The effect of number of harrow passes on wild mustard biomass. The bar is the wild mustard biomass in the unharrowed control. Average of five site-years.

At the onset of this experiment we chose treatments for harrowing based on the information that was available at that time. We chose the two leaf stage of harrowing as there earliest as this was the earliest leaf stage recommended for harrowing cereals by researchers in Eastern Canada and Europe. Unfortunately often the wild oat and wild mustard were too developed to be either uprooted or buried by harrowing at these advanced crop stages. As a result weed control was not consistent and did not result in any yield benefit. In addition the weed species we chose are difficult to control with in crop harrowing. We have observed that species such as lamb's quarters, red root pigweed and green foxtail are much easier to control with in-crop harrowing than wild oat or wild mustard. We now believe that harrowing should be done at the earliest stage possible to control these weeds, preferably when they are in the "white thread" to cotyledon stage. However this weed stage usually occurs when cereals are just emerging.

In 2006 a separate experiment was initiated at Saskatoon to try to understand the crop tolerance and weed control by post-emergence harrowing at the emergence stage of cereals. Harrowing when barely was emerging did not reduce the crop yield. However, harrowing at the one leaf stage did reduce the crop yield. As this is only one site year of data we cannot make any recommendations based on this trial but it does raise interesting questions regarding the tolerance of cereals to harrowing at very early stages.

Experiment 2.a. Tolerance of Cereal Crops to In-Crop Mowing (Saskatoon and Scott)

Equipment: A mower
Crops: Barley, Wheat, Oat
Treatments:
2.1. Crop tolerance
2.1.1.Mowing height: a) 4 cm b) 10 cm
2.1.2 Crop stage: a) 2 leaf stage b) 4 leaf stage c) 6 leaf stage
2.2 Weed Control
2.2.1.Mowing height: a) 4 cm b) 10 cm
2.2.2 Crop stage: a) 2 leaf stage b) 4 leaf stage c) 6 leaf stage

Results and Discussion:

In the absence of weeds all three cereals had good tolerance to mowing at the three leaf stage but tolerance diminished at later leaf stages (Figure 9). The best model of the data was provided by a quadratic covariance structure relating leaf stage to individual crop yield. Barley yield was reduced more than the other crops at later leaf stages as indicated by the steeper slope of the quadratic relationship. However when viewed on a relative yield basis, all three crops had similar yield reductions caused by mowing at the 4.5 and 6 leaf stage even though oat tended to have less yield reduction from the mowing (difference not significant) (Figure 10).

Averaged across all crops and environments, yield was not reduced when mowed at the 3 leaf stage, whereas yield was reduced by 13% when mowed at the 4.5 leaf stage and 27% when mowed at the 6 leaf stage. The reason that mowing at the 3 leaf stage had little effect on the yield of the crops was probably because the crop was small at this stage and the mower did very little damage to the crop. The 3 and 4.5 leaf stage of mowing probably have some potential to damage weed growth and if the crop has a higher growth rate may result in some weed control.

There was a site-year by crop by leaf stage interaction for relative yield (P=0.0115). Inspecting the results for individual site years gives some insight into the variability associated with the tolerance across environments. For the three site years that had a significant crop by site year interaction, the results differed widely (Figure 12). When site years were analyzed separately it becomes apparent that cereal crop tolerance to mowing is affected most by environment. For example the yield of barley mowed at the six leaf stage at Saskatoon in 2005 was reduced by 80% whereas at Scott in 2004 it was not reduced at all. Thus producers can not expect to have a consistent crop tolerance to mowing in different environments.

Despite the variability in yield response to mowing, there is some evidence that oat may be able to better recover from mowing due to its ability to maintain panicles when mowed at later stages. The number of oat panicles increased slightly when mowed at latter stages whereas in barley there was a reduction in heads (Figure 11). In wheat, mowing had little effect on the head density.

In summary there was little difference between the cereal crops in tolerance to mowing. Mowing at the 3, 4.5 or 6 leaf stage reduced yield 0, 13 and 27% respectively. Thus producers should avoid mowing crops at the six leaf stage.

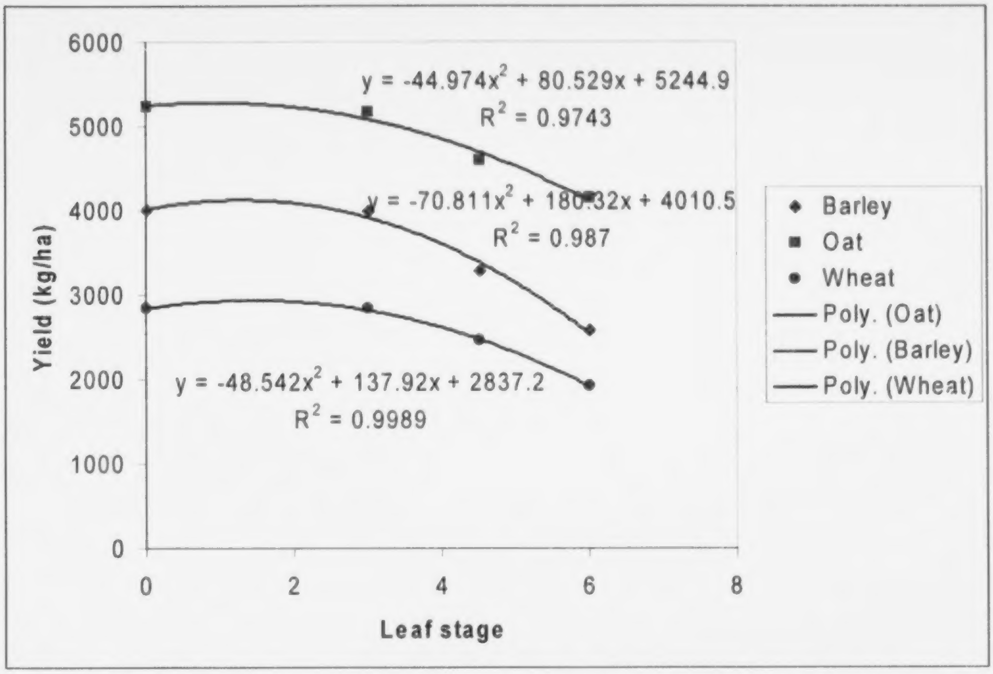


FIGURE 9. The effect of crop leaf stage on crop yield when mowed. The 0 leaf stage treatment corresponds to the un-mowed control. Average of five site-years.

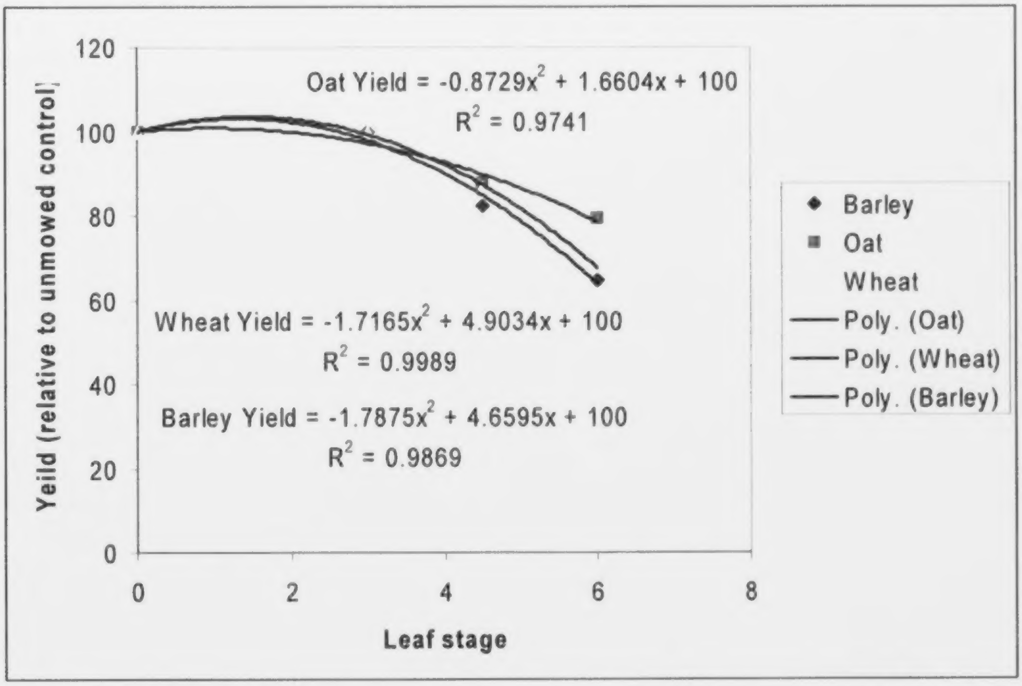


FIGURE 10. The effect of relative crop leaf stage on crop yield when mowed. The 0 leaf stage treatment corresponds to the un-mowed control. The difference between crops is not significant. Average of five site-years

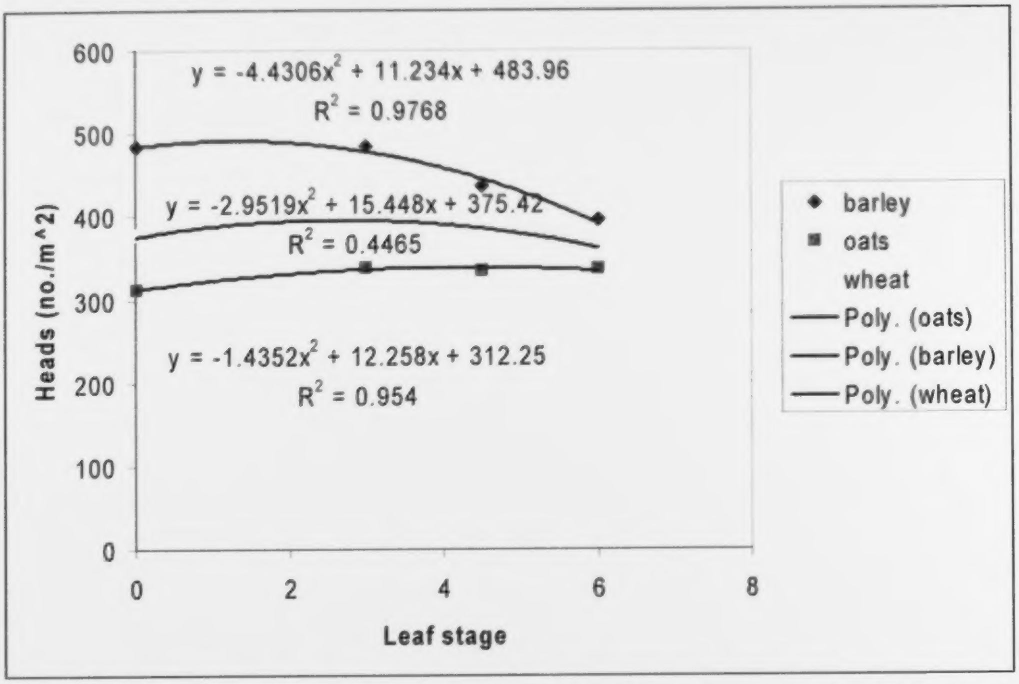


FIGURE 11. The effect of crop leaf stage on heads or panicles per square metre yield when mowed. The 0 leaf stage treatment corresponds to the un-mowed control. Average of five site-years.

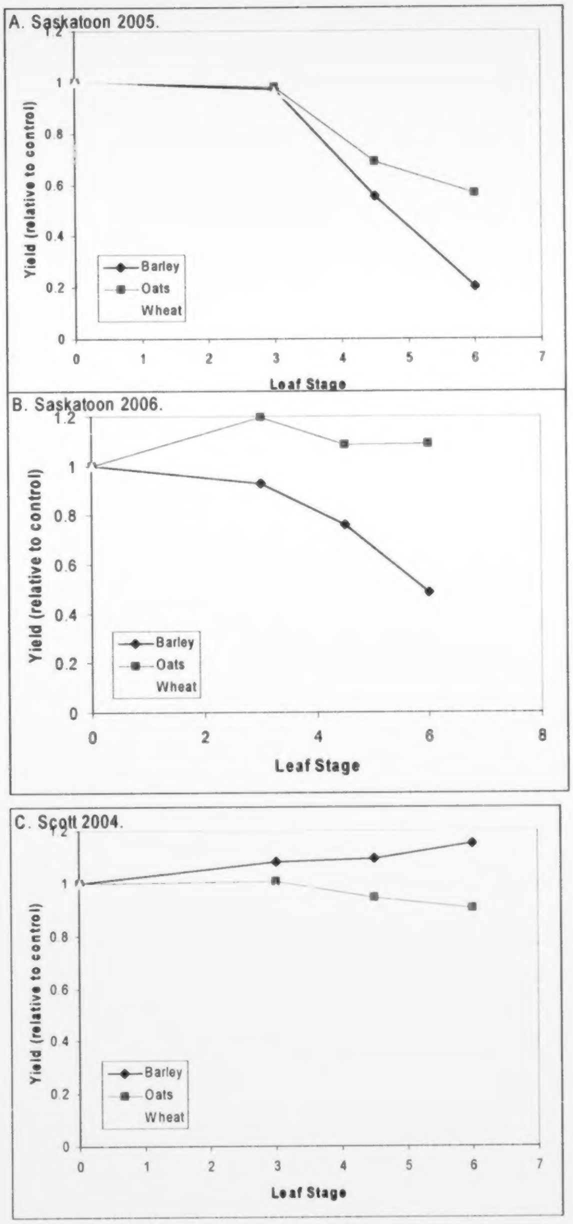


FIGURE 12. The effect of crop leaf stage on relative yield when mowed at three locations. The 0 leaf stage treatment corresponds to the un-mowed control.

Experiment 2.b. Weed Control in Wheat by In-Crop Mowing (Saskatoon and Scott)

Equipment: A mower
Crops: Barley, Wheat, Oat
Treatments:
2.2 Weed Control
2.2.1.Mowing height: a) 4 cm b) 10 cm
2.2.2 Crop stage: a) 2 leaf stage b) 4 leaf stage c) 6 leaf stage

Results and Discussion:

The yield of all crops was reduced by mowing in the presence of weeds (Figure 13). Yields were reduced when mowing was done at later leaf stages. The effect of timing of crop mowing on the yield of the three cereal crops was best modeled by using a quadratic covariate structure (Figure 13). In this model the crops differ only in the intercept of the quadratic model. The effect of mowing on the yield reduction in the crops was the same indicating that the crop yield response to mowing was similar. As the overall effect mowing stage on yield of is expressed on an absolute yield basis the effect on relative yield was greatest for wheat which had a lower un-mowed yield (intercept) than the other crops ($P<0.01$). The yield of barley and oat did differed at the $P=0.092$ level.

There was an interaction between cereal species and the time of mowing for total weed biomass ($P<0.001$) (Figure 14). Weed biomass was reduced when oat was mowed at the crop six leaf stage. In contrast weed biomass increased when wheat was mowed at the six leaf stage. A more clear understanding of the effect of mowing on weed biomass is apparent when the weed biomass is separated by species. Wild mustard biomass was reduced in all crops when mowed at the 4.5 or 6 leaf stage to an average for all crops of 78% and 36% of the un-mowed control respectively (Figure 15). However mowing at the three leaf stage actually increased wild mustard biomass to an average of 132% of the un-mowed control. In contrast, mowing never reduced wild oat biomass (Figure 14). Mowing actually increased wild oat biomass in wheat when mowed at the six leaf stage compared to not mowing ($P<0.01$).

For both weed species, barley allowed the least weed biomass compared to the other crops (Figure 15 and 16). This is probably because barley is a better competitor with weeds than oat or wheat. Analyzing just the weedy and weed-free treatments separately indicates that barley yield is affected less by weeds than oat or wheat (Interaction $P=0.05$) (Figure 17). In terms of percent yield loss from weeds, barley had 11%, oat 22% and wheat 24% yield loss.

Although mowing was effective at reducing wild mustard biomass, this biomass reduction never resulted in a crop yield increase. It could be argued there may have been a positive effect if we were just attempting to control wild mustard. However with the exception of wheat at the 6 leaf stage, mowing did not usually have an effect on wild oat biomass. Thus the effect of wild oats on the removal of wild mustard competition would be mostly neutral. Using this logic it appears that mowing as a weed control technique is not warranted. Even in the absence of weeds mowing at the 4.5 and 6 leaf stage resulted in a yield that was 84% and 66% of the control.

Based on the results of a crop tolerance and weed control experiment it is our recommendation that producers not use mowing to attempt to control weeds in cereals. While mowing at the 4.5 and 6 leaf stage was effective at reducing wild mustard biomass the damage done to the crop by this mowing resulted in a crop yield that was lower than when mowing was not done at all.

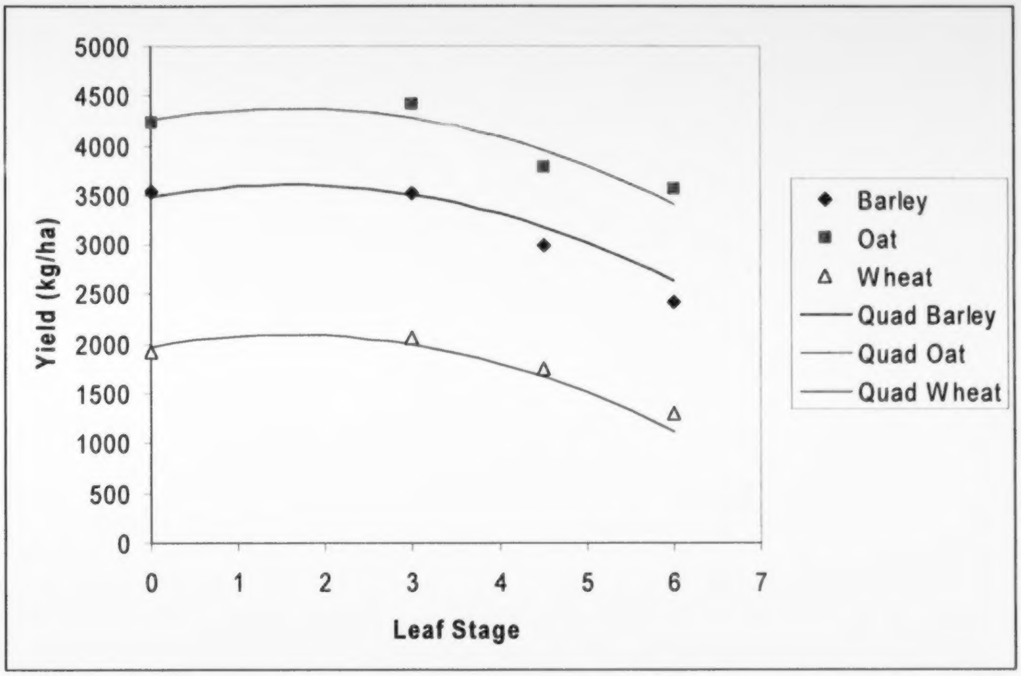


FIGURE 13. The effect of crop leaf stage on crop yield when mowed. A quadratic covariance structure was used where Crop yield = Intercept + 156*Leaf Stage -49.6*(Leaf Stage)^2. The 0 leaf stage treatment corresponds to the un-mowed control. Average of five site-years.

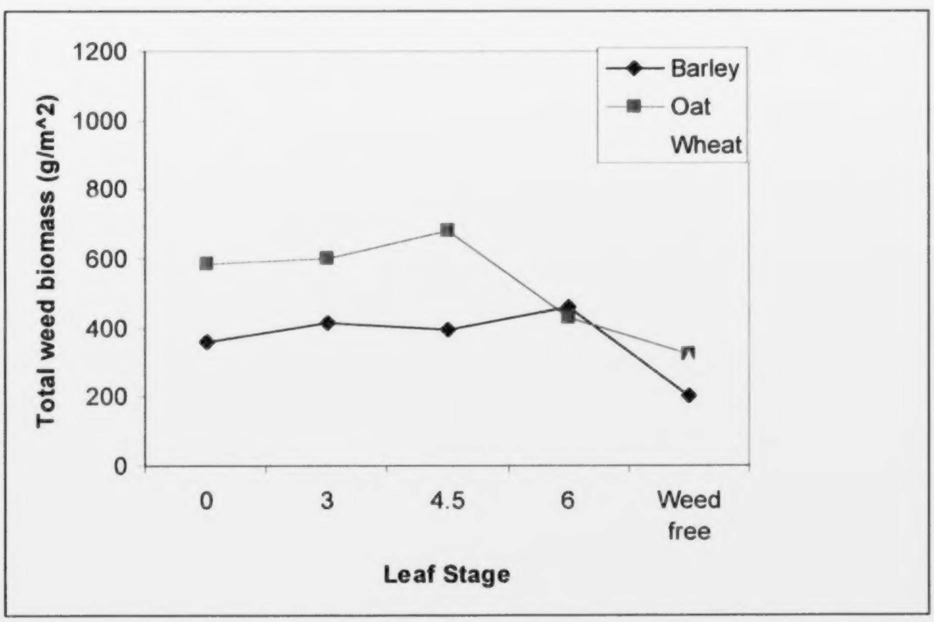


FIGURE 14. The effect of crop leaf stage on total weed biomass when mowed. The 0 leaf stage treatment corresponds to the un-mowed control. Average of four site-years.

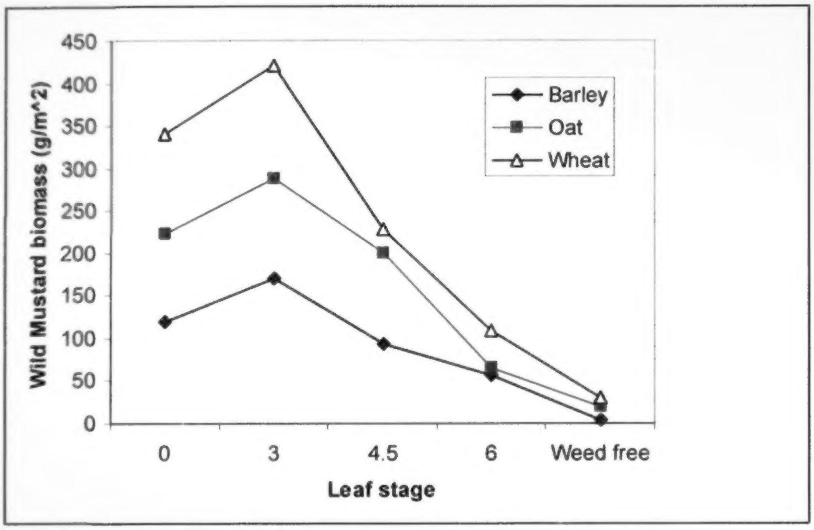


FIGURE 15. The effect of crop leaf stage on wild mustard biomass when mowed. The 0 leaf stage treatment corresponds to the un-mowed control. Average of four site-years.

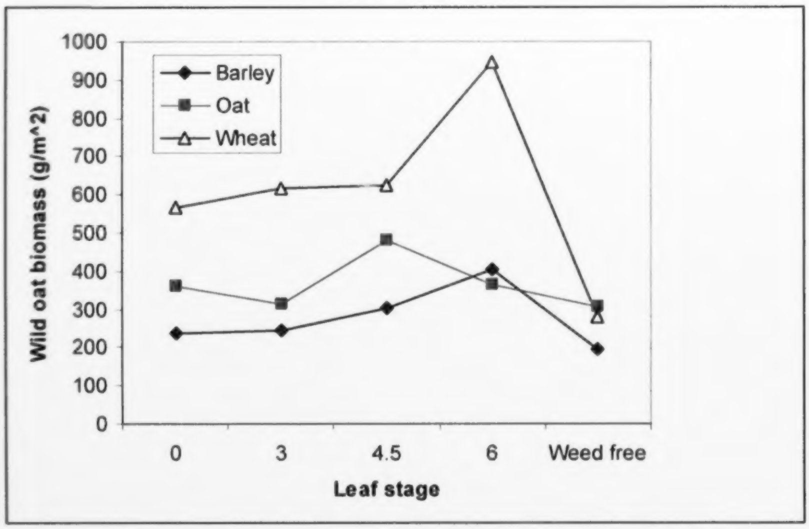


FIGURE 16. The effect of crop leaf stage on wild oat biomass when mowed. The 0 leaf stage treatment corresponds to the un-mowed control. Average of four site-years.

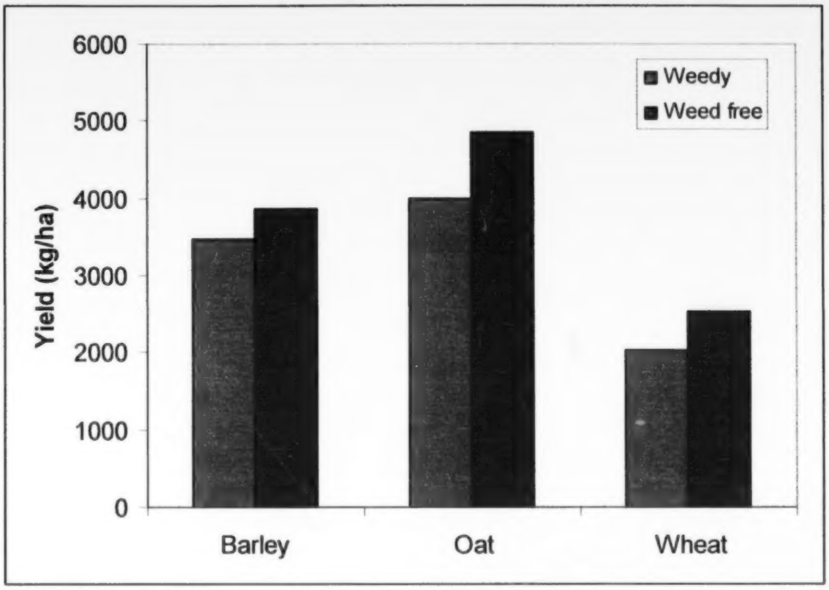


FIGURE 17. The effect of weeds presence or absence on crop yield in three cereals. Average of four site-years.

Experiment 3.a. Flax Tolerance to rolling (Saskatoon only)

3. Rolling (Saskatoon only)
Equipment: A field land roller
Crops: Flax
Treatments
3.1. Flax tolerance
Flax stage a) 10cm high b) 20cm high c) budding d) early flower e) late flower

Results and Discussion:

There were significant differences between treatments for the effect of rolling on flax yield in the absence of weeds ($P<0.001$). Rolling at the early flowering stage or later resulted in an average decrease in flax yield of 36% (Figure 14). In contrast rolling the flax up to the early bud stage did not result in a statistically significant yield loss. The yield loss at flowering appears to be as a result of reduced stem density (Figure 15) . The rolling operation reduced stem density from the bud stage on. Interestingly, although rolling the flax at the bud stage reduced the stem density (Figure 15), it did not reduce the yield. Apparently flax yield can compensate for reduced stem density at this stage.

Based on yield loss in the absence of weeds, flax can tolerate rolling up to the early bud stage with no significant reduction in yield. Inspection of results from individual years of this experiment reveal that there was never a yield loss associated with rolling the flax up to and including the early bud stage. However, rolling at the early bud stage does reduce the amount of stems per length of row. Because of this it may be safe to only roll flax before the bud stage has begun. Based on visual observation it appears that flax rolled later does not always stand back up. In addition some of the stems die. Both of these factors are assumed to contribute to the yield loss observed.

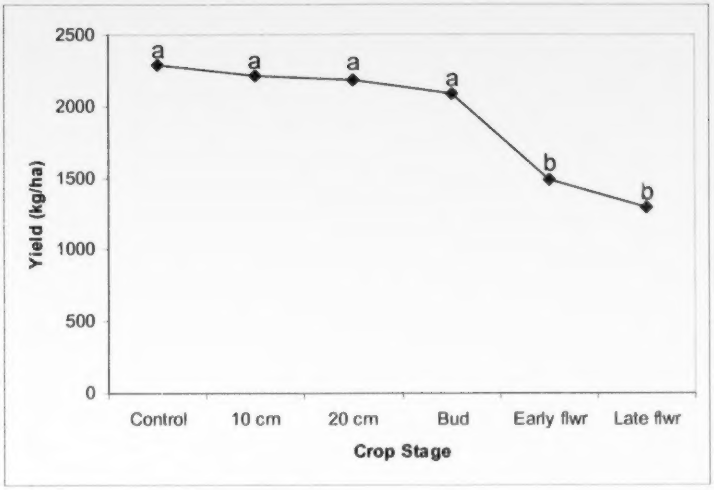


FIGURE 18. The effect of crop stage on flax yield when rolled. Means with different letters signify a significant difference ($P<0.05$). Average of three years.

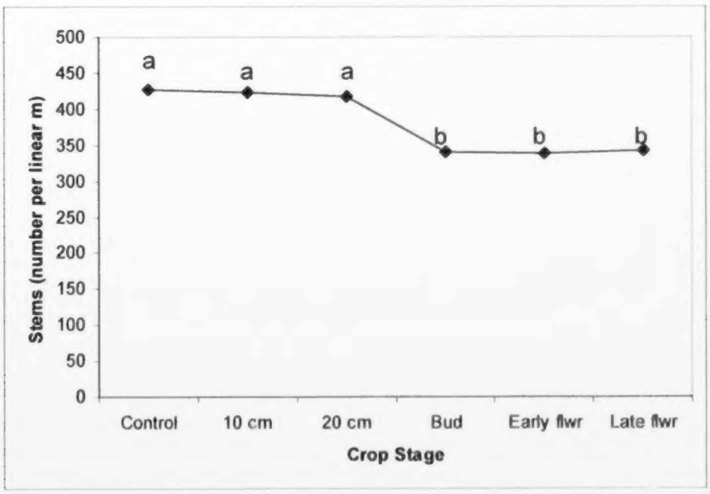


FIGURE 19. The effect of crop stage on stem density of flax when rolled. Means with different letters signify a significant difference ($P<0.05$). Average of three years.

Experiment 3.a. Broadleaf Weed Control in Flax by rolling (Saskatoon only)

3. Rolling (Saskatoon only)
Equipment: A field land roller
Crops: Flax
Treatments
3.2. Broadleaf weed control (wild mustard was used as the test weed species)
Weed stage a) 6 leaf b) bolted c) early flowering d) late flowering

Results and Discussion:

There were significant differences between treatments for the effect of wild mustard stage at rolling on wild mustard fresh biomass ($P<0.001$). Rolling the wild mustard during the flowering stages reduced biomass by 32% compared with rolling during the vegetative stages of wild mustard (contrast $P=0.0002$) (Figure 20). Nevertheless rolling the flax during flowering resulted in a flax yield that was on average 46% lower than rolling it during the vegetative stage (contrast $P=0.0001$) (Figure 21). None of the treatments resulted in a yield increase in flax even though the weeds were not controlled in the unrolled control treatment (Figure 21).

The reason for initiating this experiment was that it was believed that the rolling would break the wild mustard stems whereas the more resilient flax stems would not break. While this differential stem breakage was observed to be true when rolling occurred during the wild mustard flowering stage, the broken wild mustard plants effectively held down the flax plants and prevented them from springing back. As a result, the harvest operation was also impeded.

Based on the results of this experiment and the previous tolerance experiment, we can thus conclude that there is no yield benefit to rolling flax. A reduction in wild mustard biomass does occur when rolling is performed during the wild mustard flowering stage. However this does not result in a higher flax yield. On the contrary, flax yields are reduced, probably because of the reduced tolerance of flax to rolling at this stage observed in the rolling tolerance experiment (Figure 18). Based on these results an organic flax grower would be advised to tolerate wild mustard growing in flax and not attempt to control it by rolling. Other alternative weed control methods such as weed clipping have been shown to reduce the wild mustard seed output while not negatively affecting flax yield.

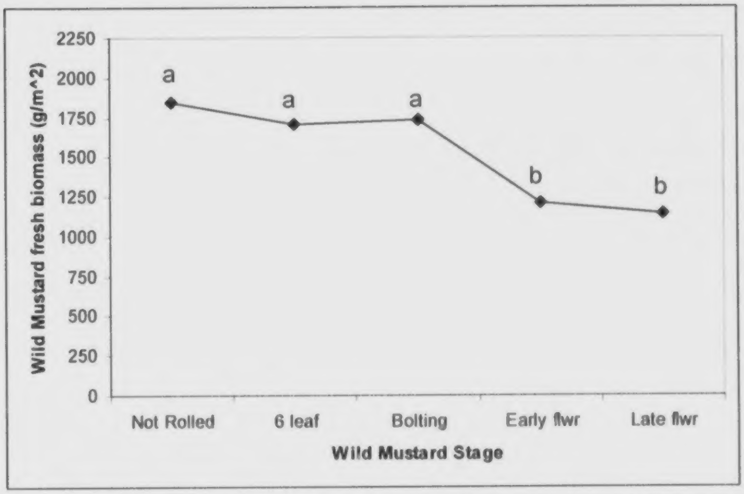


FIGURE 20. The effect of wild mustard rolling stage on wild mustard biomass. Means with different letters signify a significant difference ($P<0.05$). Average of three years.

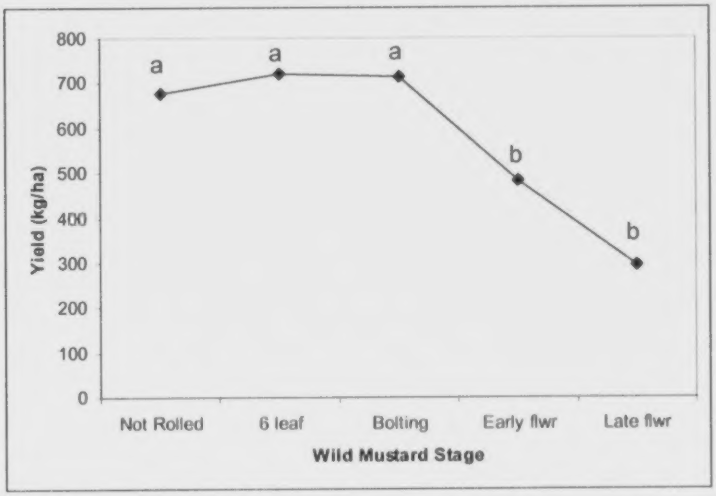


FIGURE 21. The effect of the wild mustard rolling stage on flax yield. Means with different letters signify a significant difference ($P<0.05$). Average of three years.

Rotary Hoe for Weed Control in Field Pea – Scott - 2005

Rotary hoe in field pea

Objectives:

- To assess the ability of a minimum till rotary hoe to operate in standing stubble and to maintain surface residues;
- To assess the tolerance of field pea to rotary hoeing at different crop stages and hoeing intensities;
- To define the timing and number of passes to optimize weed control in field pea with a minimum-till rotary hoe.

Materials and Methods

Tolerance and weed control treatments were arranged in a split block design. Within each block, the factorial treatments of crop stage and number of passes were arranged in a split-plot design with crop stage being the main plot and number of passes being sub-plot.

Factorial Experiment
Factors (2):
1. Crop Stage (5): Pre-emergence; Ground crack; 5-node stage of crop (includes 2 below ground nodes); 8-node stage of crop (includes 2 below ground nodes);11 node stage of crop (includes 2 below ground nodes)

2. Number of passes (7): 0, 1, 2, 3, 4, 5, 6 passes.

Plot size (m): 1 .5 x 6.0 metres
Replicates: 4
Crop (s) / Cultivar (s): Field Pea / CDC Sonata
Seeding Implement (hoe, disc): Atom Jet Single Shoot Hoe
Row Spacing: 25.4 cm
Seeding rate (crops): 80 plants/m^2
Planting Depth: Field pea (5 cm)
Inoculants: Granular applied with the seed at 11 Kg/ha.
Weed (s) Seeded: Wild Mustard & Green Foxtail
Weed Seeding Implement: Double disc press drill
Weed Seeding Rate: 100 seeds m^{-2} for each species.

Previous crop: Spring Wheat
Field pea was directed seeded into standing wheat stubble.

Soil Information:
Dark Brown Chernozemic (Typic Boroll)
Association: Scott
Texture: Loam Sand: 31% Silt: 42% Clay: 27%
Organic Matter: 4%
Soil pH: 6.0
Data Collection

To assess the effect of rotary hoeing on crop surface residues, digital photos of each treatment (no. of passes) were taken when the field pea was hoed at the pre-emergence stage. A grid was then overlaid on the photos and surface residue estimated.

Tolerance data included number of field pea plants, and crop yield in all years. Weed control densities and biomass was collected in 2004 but not in 2005 or 2006 due to severe damage from hail storms. Hail caused severe damage to the weedy plots resulting in a tangled mess and data collection was impossible. Yields from the weedy plots were taken in 2004 and 2006. Therefore, only 2 years of yield data are reported from the weedy plots.

Data analysis was done with using PROC GLM in SAS. Combined data from all years are presented. In the analysis, year and year X treatment interactions were considered a random effect.

Results and Discussion

Surface residue

Surface residue declined slightly as the number of passes increased; however, the number of passes (0 to 6) did not result in a statistically significant effect (*p = 011*) (Table 3)

Table 3: Effect of number of rotary hoe passes on surface crop residue ground cover (%). Rotary hoe treatments were applied at the pre-emergence stage of field pea seeded on spring wheat stubble. Scott. 2004-06.

No of passes	% surface residue
0	64
1	61
2	58
3	61
4	56
5	59
6	55
$LSD_{0.05}$	12
CV	13

Crop Tolerance

There was a significant crop stage X number of passes interaction on field pea density (Table 4). At the earliest stages, plant density declined after 3 to 4 passes; however, after the crops became well anchored (8- to 11-node stage, there was no stand reduction. Even though the plants had not emerged at the pre-emergence stage, field pea seeds were brought to the surface as the number of passes increased (personal observation). This likely explains the reason for some mortality at this stage.

Crop stage had no effect on field pea yield and there was no crop stage X number of passes interaction (Table 3). The number of passes had an effect, independent of crop stage (Table 3). After 2 passes, yields declined by 5 to 6% (Figure 23).

Table 4: ANOVA for field pea tolerance to rotary hoeing study. Scott. 2004-06.

Source	Field Pea Density ($\# \ m^{-2}$)	Field pea Yield ($kg \ ha^{-1}$)
Crop Stage (CS)	0.21	0.60
No. of Passes (NP)	0.10	0.01
CS X NP	0.04	0.55

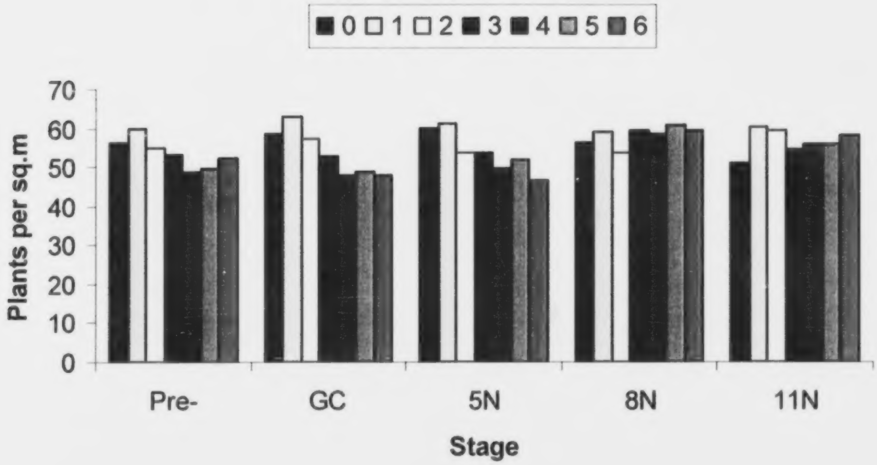


Figure 22: Interaction of crop stage and number of rotary hoe passes on field pea density (plants/m^{-2}). Pre- = pre=emergence stage, GC=ground crack, 5N, 8N, and 11N = 5, 8 and 11 total nodes, respectively. Scott 2004-06.

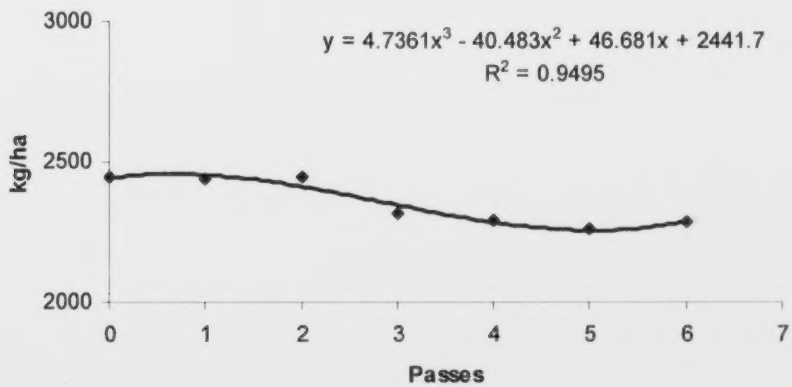


Figure 23: Effect of the number of rotary hoe passes on yield of field pea (tolerance study). Mean of 5 timings. Scott. 2004-06.

FIELD PEA YIELDS UNDER WEEDY CONDITIONS

Although weed data was not collected, the yields from the weedy plots from 2004 and 2006 provide some additional insight. Crop stage had an effect with the ground-crack stage, having the highest yields and the 8-node stage the lowest yields (Table 5). This is likely due to the stage of the weeds. Even though there was not a statistically significant crop stage X passes interaction, there is an indication that there was a linear yield increase to the number of passes at the pre-emergence stage and three passes improved yield in the range of 30% at the ground-crack stage (Figure 24). At other stages, the number of passes had no effect on crop yield.

Table 5: Effect of crop stage at which rotary hoeing was conducted on yield of field pea (kg/ha). Mean of 0-6 passes. Scott. 2004 and 2006.

Crop stage	Pea yield (kg/ha)
Pre-emergence	889.89
Ground crack	945.96
5-node	894.79
8-node	776.77
11-node	859.71
$LSD_{0.05}$	132

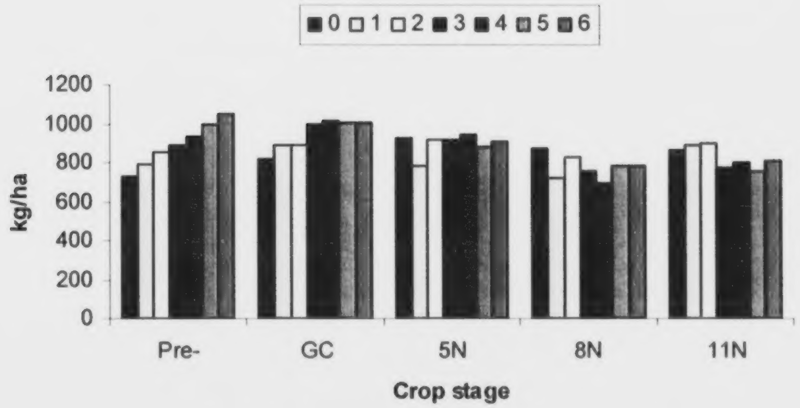


Figure 24: Effect of the number of rotary hoe passes at various crop stages on the yield of field pea in weedy conditions. Scott. 2004 and 06.

Conclusions

- The rotary hoe was able to maintain crop residues on the surface.
- Under weed-free conditions, field pea density was not reduced when rotary hoeing was conducted after the 8-node stage. At earlier stages of crop development, the reduction in plant density was in the order of 8 to 20%.
- Under weed-free conditions, field pea yields were reduced after 2 passes. Under weedy conditions, there appears to be some improvement in yields at the pre-emergence and ground-crack stage. At the pre-emergence stage, additional passes improved yield even after the 6 passes. At the ground-crack stage, 3 passes optimized field pea yield.

Tolerance of Spring Wheat to Rotary Hoeing

Objectives:
- To assess the tolerance of spring wheat to rotary hoeing at different crop stages and hoeing intensities;
- To assess weed control in spring wheat with the rotary hoe at different crop stages.

Materials and Methods

Experimental Design: Tolerance and weed control treatments were arranged in a split block design. Within each block, the factorial treatments of crop stage and number of passes were arranged in a randomized complete block

Treatment Design: Factorial
Experiment Factors (2):

1. Timing
   - Pre-emerge
   - 1-2 leaf stage of wheat
   - 4-5 leaf stage of wheat

2. Number of passes
   - 0-6 passes

Plot size (m):	5m wide x 8 m long
Crop (s) / Cultivar (s):	wheat – Eatonia
Crop Seeding Date:	May 16, 2005
Seeding Implement (hoe, disc):	hoe drill
Row Space:	7 inch
Seeding rate (crops):	95 kg/ha (250 seeds m^{-2})
Planting Depth:	5 cm

Dark Brown Chernozemic (Typic Boroll)

Association: Scott

Texture: Loam Sand: 31% Silt: 42% Clay: 27%

Organic Matter: 4%

Soil pH: 6.0

Results

Crop Tolerance

Data were combined for all three years and analyzed with the PROC GLM procedure of SAS. Years and year X treatment interactions were considered a random effect

Rotary hoeing at any crop stage or the number of passes had no effect on spring wheat density or crop yield (Table 6; Figure 25). Rotary hoeing at any crop stage did not affect spring wheat head density; however, the number of passes had an effect (Figure 26). Heads per m^2 declined slightly up to 4 passes, and then stabilized after that.

Table 6: ANOVA for spring wheat tolerance to rotary hoeing study. Scott. 2004-06.

Source	Spring Wheat Plants (# m^{-2})	Spring Wheat Heads Density (# m^{-2})	Spring Wheat Yield (kg ha^{-1})
Crop Stage (CS)	0.29	0.99	0.37
No. of Passes (NP)	0.16	0.03	0.17
CS X NP	0.18	0.14	0.89

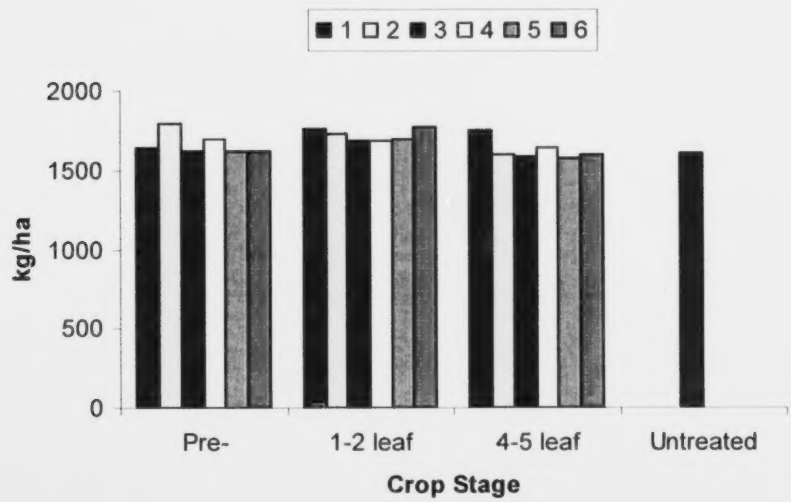


Figure 25: Effect of crop stage and number of rotary hoe passes on spring wheat yield. Scott. 2004-06.

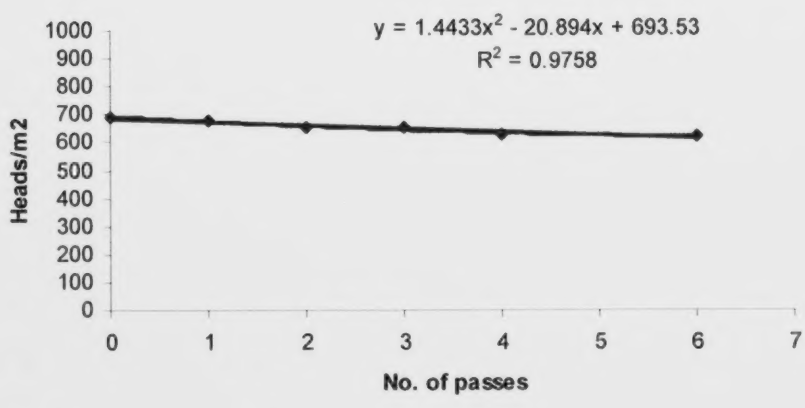


Figure 26: Effect of number of rotary hoe passes on spring wheat heads per m^2. Scott. 2004-06.

Weed control

Weed densities were low in both 2004 and 2006. Only 2005 resulted in weed densities where rotary harrowing had an effect. However, there were some yield trends in 2004 and 2005 that assist in making recommendations.

Weed control in 2005

Timing and number of passes had an effect on weed density and weed biomass production; however, there was no interaction between the two factors. Lowest volunteer canola and green foxtail densities were recorded when hoeing was conducted at the 1-2 leaf stage (Table 7). Lowest total weed biomass was recorded at the pre-emergence to 1-2 leaf stage.

The optimum number of passes to reduce volunteer canola and green foxtail density was three to four (Figs. 25 and 26). Lowest weed biomass was recorded with two to three passes (Fig. 27).

Table 7: Effect of timing of rotary hoeing on weed density and fresh weight in spring wheat. Mean of six passes. Scott. 2005

Crop Stage	Volunteer canola density ($\#/m^2$)	Green foxtail density ($\#/m^2$)	Weed fresh weight (g/m^2)
Untreated	138	39	337
Pre-emergence	82	48	225
1-2 leaf	54	14	251
4-5 leaf	99	20	305
$LSD_{0.05}$	28	11	59

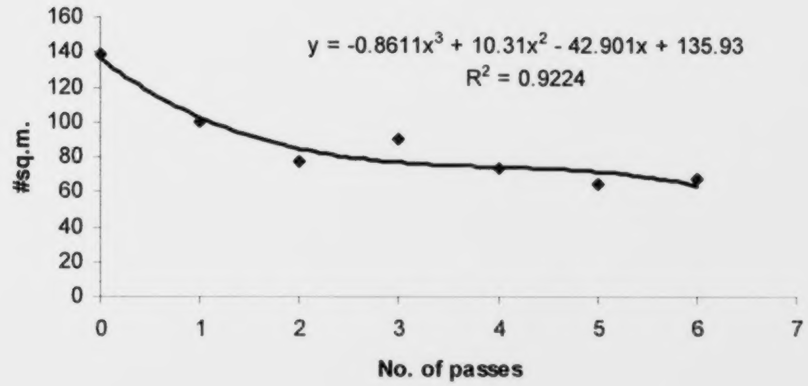


Fig. 27: Effect of number of rotary hoe passes on the density of volunteer canola in spring wheat. Mean of three crop stages. Scott, SK. 2005.

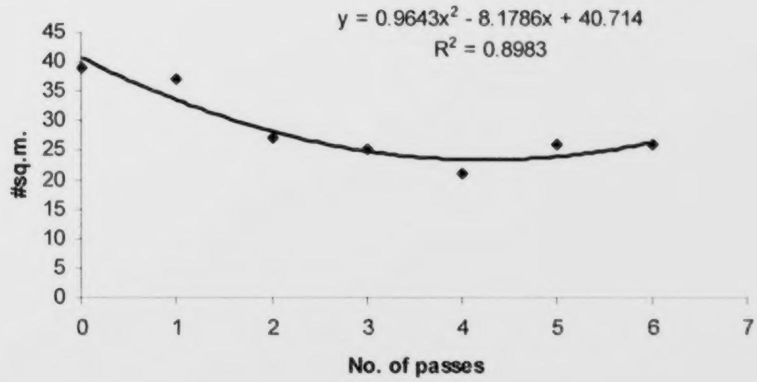


Fig. 28: Effect of number of rotary hoe passes on the density of green foxtail in spring wheat. Mean of three crop stages. Scott, SK. 2005.

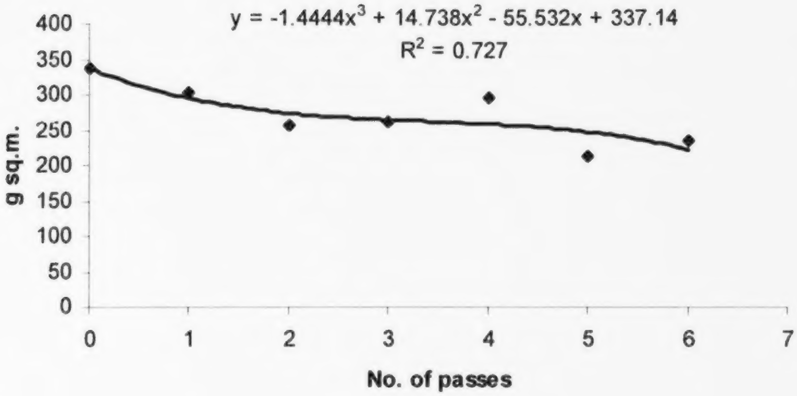
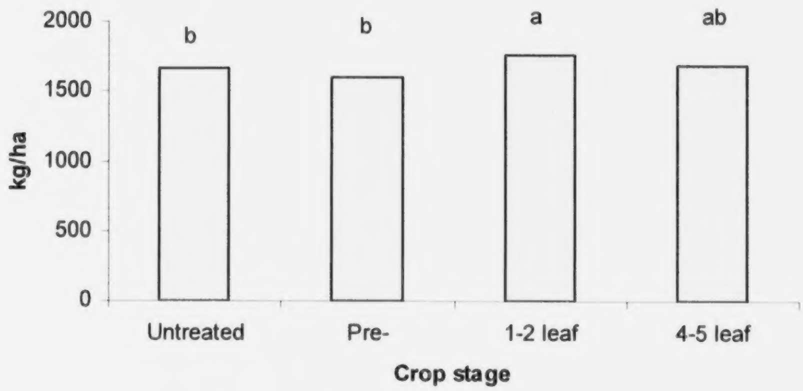


Fig. 29: Effect of number of rotary hoe passes on weed fresh weight in spring wheat. Mean of three crop stages. Scott, SK. 2005.

Spring wheat yield under weedy conditions 2004-2005.

In both years, rotary hoeing at the 1-2 leaf stage resulted in the highest yields (Figure 30) indicating that timing may be optimum timing of weed removal.

2004



2005

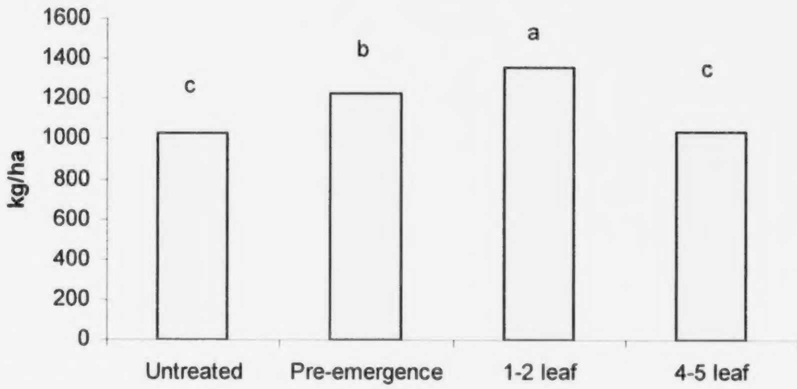
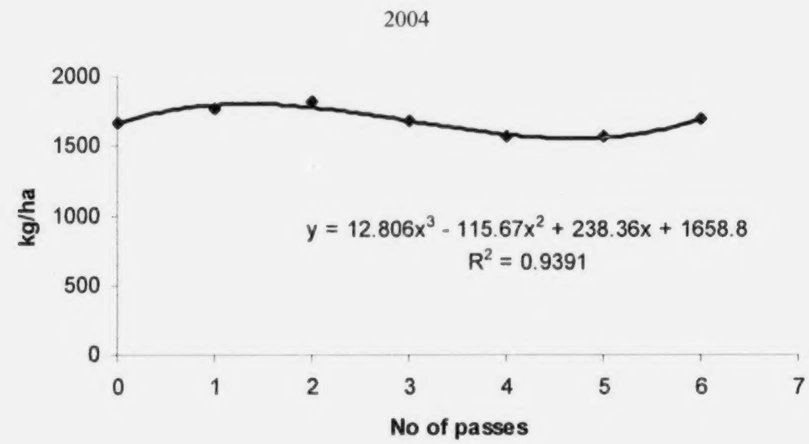


Fig. 30: I ... 04 and 2005.

Yields were optimized at 2 passes and 4 passes in 2004 and 2005, respectively (Fig. 31).



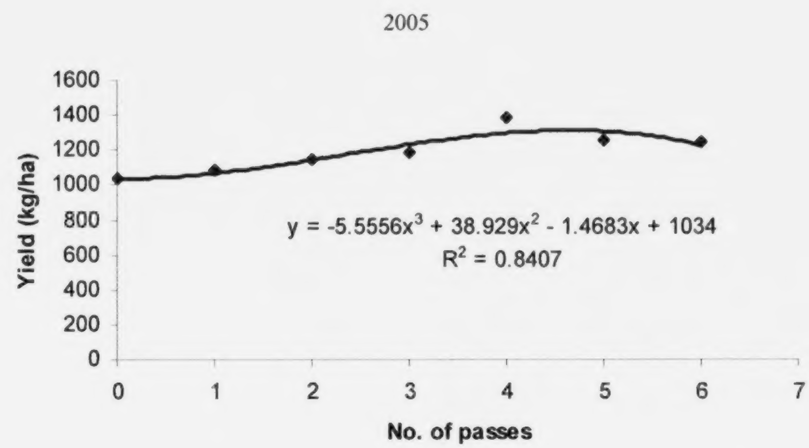


Figure 31: Effect of number of rotary hoe passes on yield of spring wheat in weedy conditions. Mean of three timings. Scott, SK. 2004 and 2005.

<u>Conclusions</u>

- Spring wheat tolerated hoeing at all stages. Under weed-free conditions, wheat heads per square meter declined slightly with increasing number of passes; however, this did not result in lower yields as the crop was able to compensate.
- Hoeing at the 1-2 leaf stage was the optimum stage for reducing weed density in 2005 and achieving highest yields in 2004 and 2005. Two to four passes with the rotary hoe resulted in highest yield depending on year.

3.4 Information of Benefit to Producers, Processors or Government

All of the above information is of direct benefit to producers.

4 Personnel

A personnel report will be supplied.

5 Equipment

No equipment was purchased.

6 Project Developed Materials

No project materials are yet available.

7 Project Photos

None at this time.

8 Acknowledgements

Soils and Crops 2005, 2006 Canadian Weed Science Society Meetings, 2006 North Central Weed Science Society Meetings by Shirtliffe, various extension talks by E. Johnson.

9 Expense Statement

An expense statement has been supplied by the U of S business office.

10 ICAR Registration

This project is being registered with ICAR.